

# React and Wind Magnets with $\text{Nb}_3\text{Sn}$ and Bi-2212

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# Outline of the Presentation

## HTS and Hybrid Magnets with Bi-2212:

A brief report on encouraging results (see poster for details)

- Bi-2212 can produce round wires for high current Rutherford cables.
- React & Wind appears to be the most likely choice for any reasonable length magnet made with Bi-2212 cable because of the requirements of a high reaction temperature and a high temperature uniformity throughout.

## React & Wind Technology for Nb<sub>3</sub>Sn Magnets:

### Mixed results

- Reached short sample in 1<sup>st</sup> quench in the first magnet, but not in later.
- It is too early to be even thinking about making a choice between “Wind and React” Vs. “React & Wind”, as many issues are yet to addressed.

# HTS in Accelerator Magnets

## Two Types of HTS Applications:

- **High field low temperature applications**

These application include possible hybrid magnets.

We can benefit from a factor of ~2 improvement in HTS performance.

- **Medium field high temperature (20 – 40 K) applications**

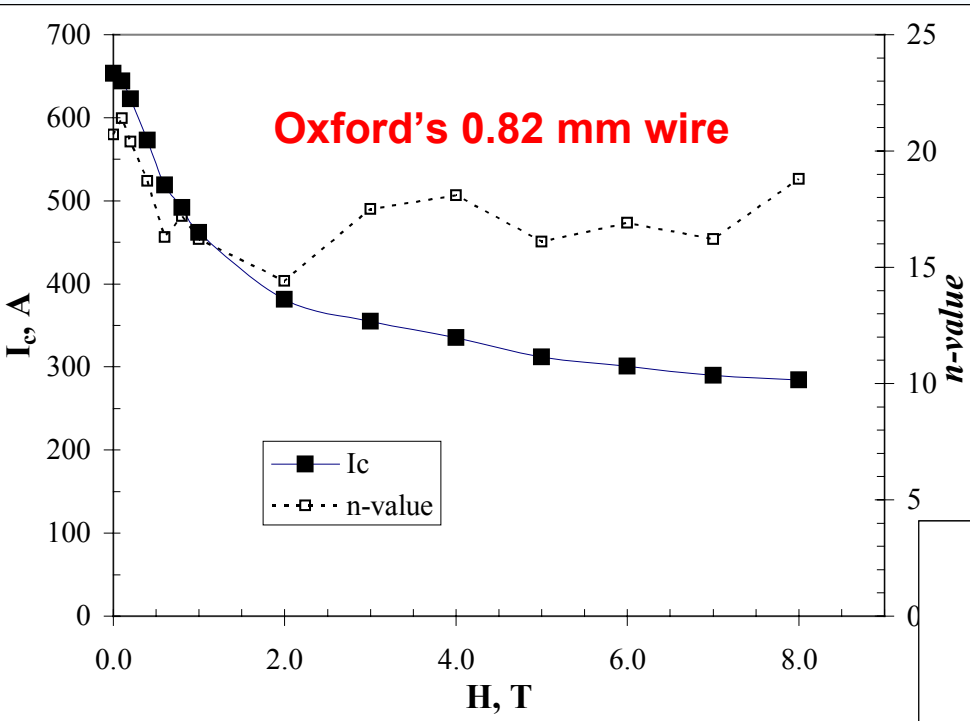
These applications are based on the commercially available HTS today.

**In both cases, HTS offer several unique advantages. HTS allow large energy deposition, higher operating temperature, economical heat removal, larger variations in operating temperature, etc., etc.**

# Bi-2212 Wires from Oxford & Showa

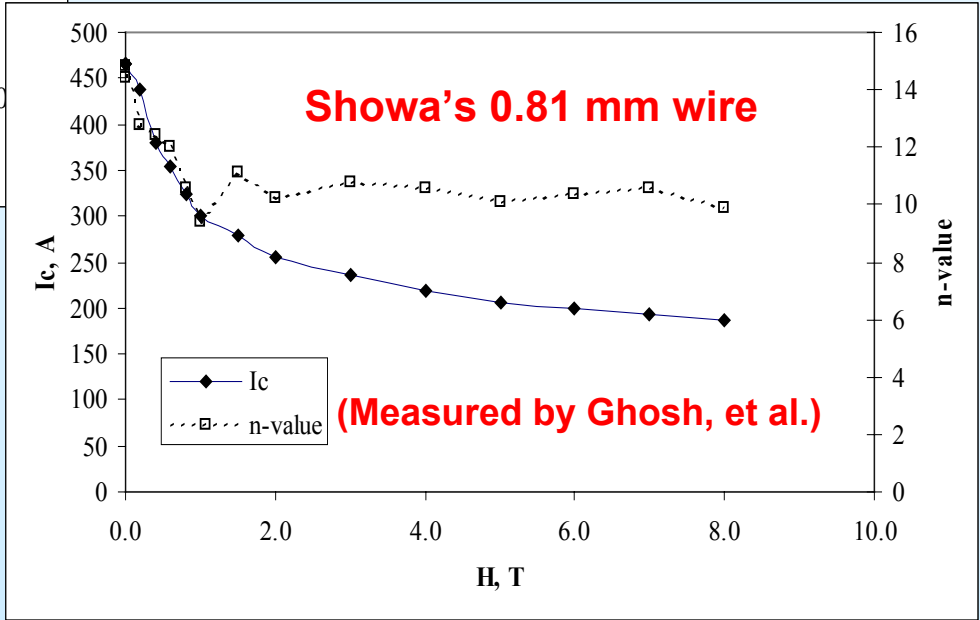
We are very pleased to note that Oxford is now making quality round wires of BSCCO-2212.

These measurements are not for the best wires from Oxford and Showa. But they indicate that both can now achieve a nice comparable performance (but we want more).

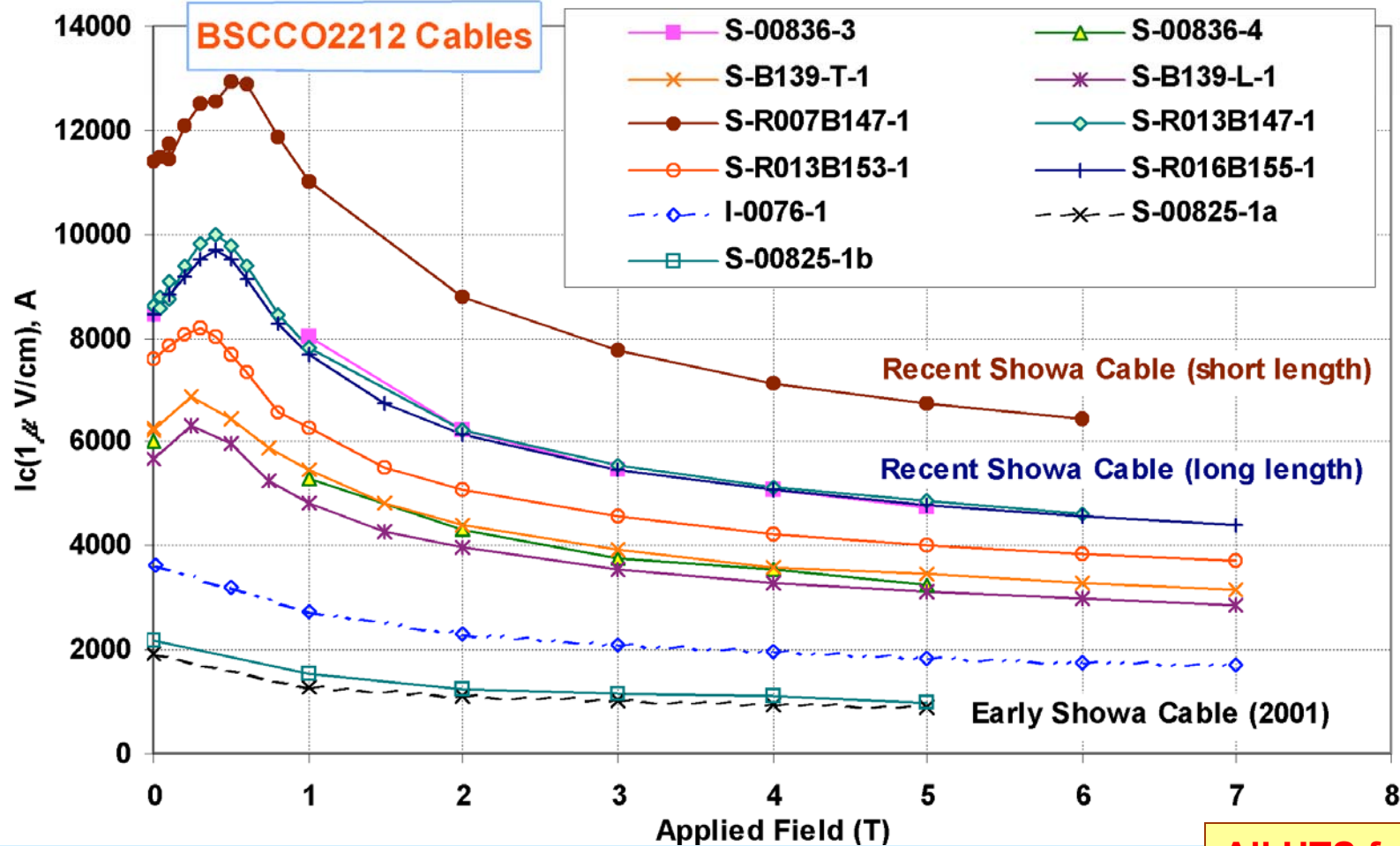


Present High field  $J_c \sim 2\text{kA/mm}^2$

Wire ID	No. of Fils	Diameter	$J_c$ (1T)	$J_c$ (5T)
		mm	A/mm <sup>2</sup>	A/mm <sup>2</sup>
B1152	127x7	1.00	2617	1863
PMM030224	85x7	0.82	3076	2080
PMM030224	85x7	0.72	2738	1872



# HTS Cables: A Remarkable Progress



Significant  
self-field at  
high  
currents.

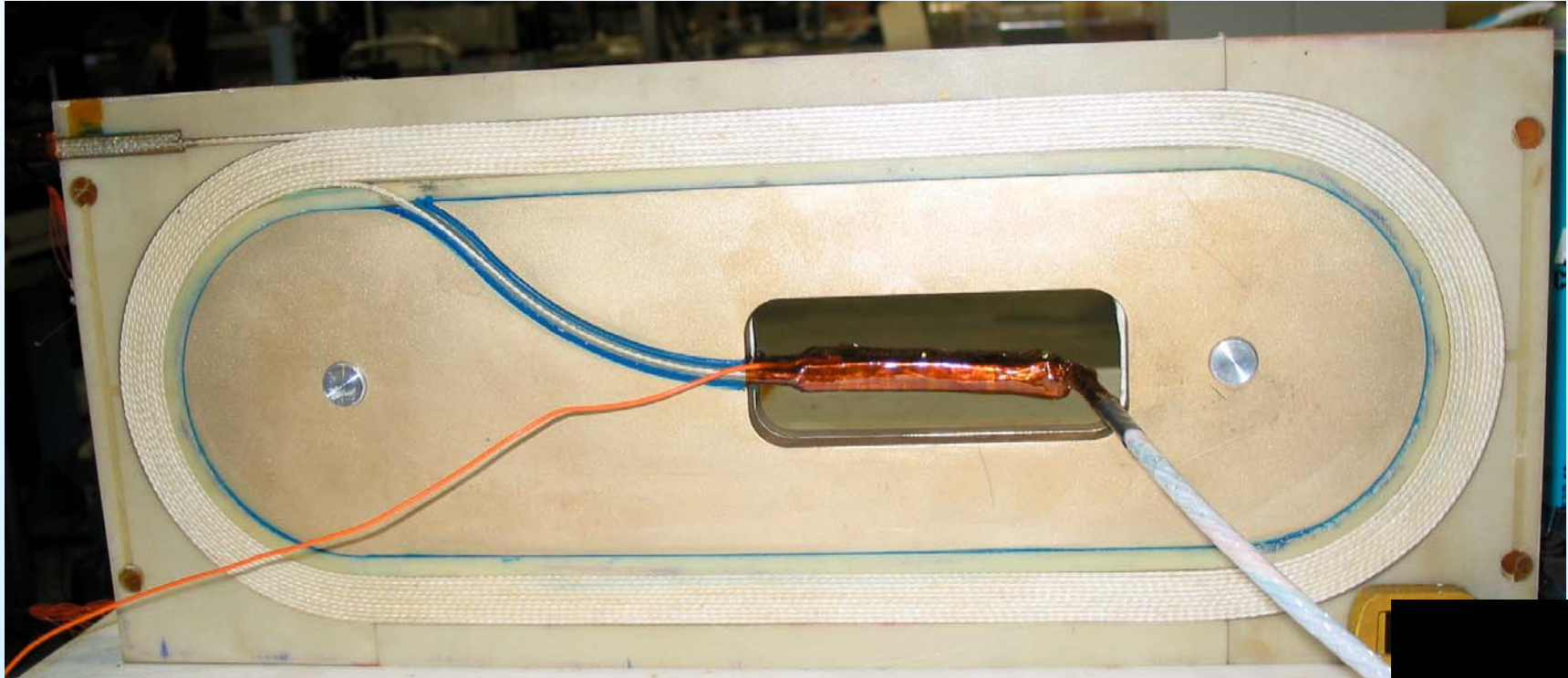
HTS  
Cables  
Tested  
at BNL  
Short  
Sample  
Test  
Facility

All HTS from Showa.  
Cables made at LBL.  
Thanks Ron.

➡ Modern HTS Cables Carry A Significant Current.

# HTS Coils for Accelerator Magnets

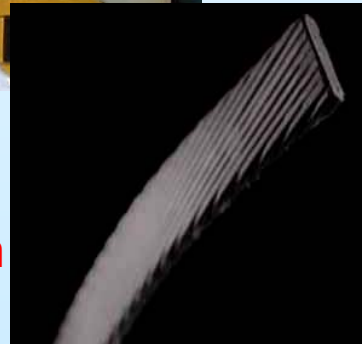
We use “Rutherford cables” in “conductor friendly” accelerator magnet designs using “racetrack coils” and “React & Wind technology”.



A 10-turn racetrack R&D coil recently built and tested at BNL.

Minimum bend radius 70 mm; Cable thickness ~1.6 mm.

Bending strain 1.2% or 0.6% depending on whether the wires in the cable are sintered or not (they definitely are at the edges).



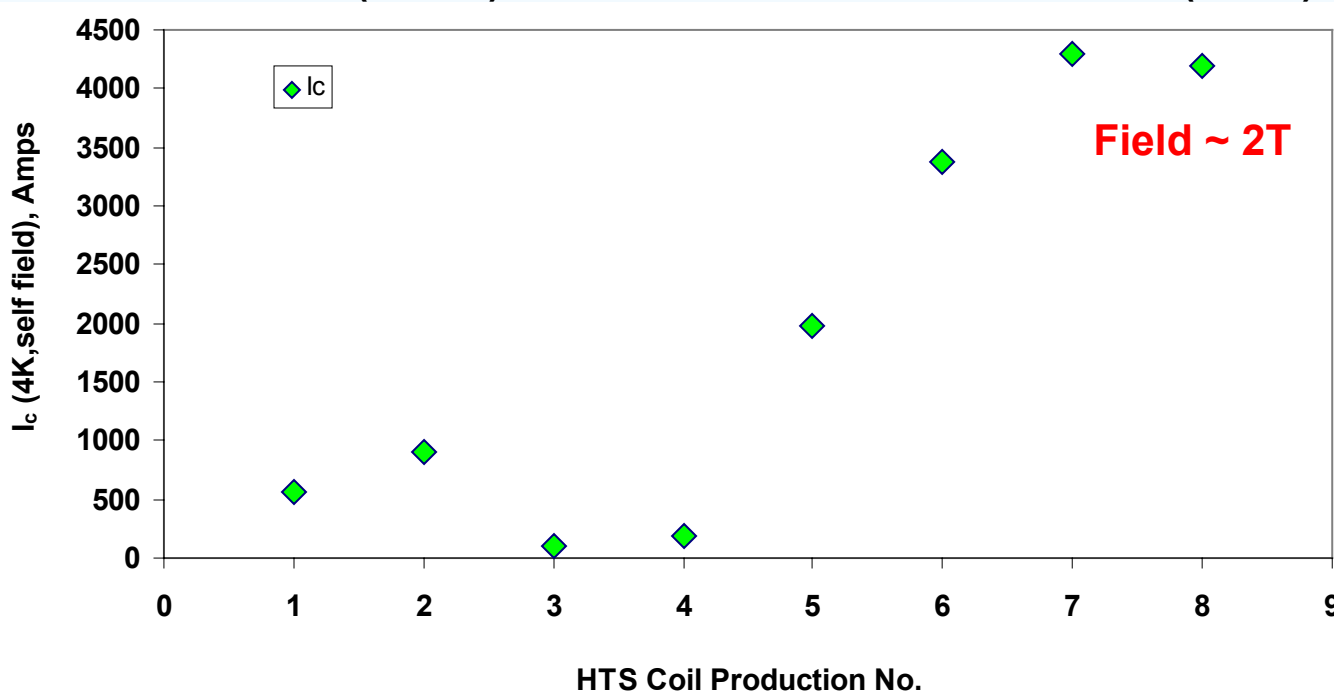


## 4.2K Test Results of HTS Coils

Earlier coils  
<1 kA (~2001)

Measurements  
in self-field

Latest coils  
4.3 kA (10/03)



Note:

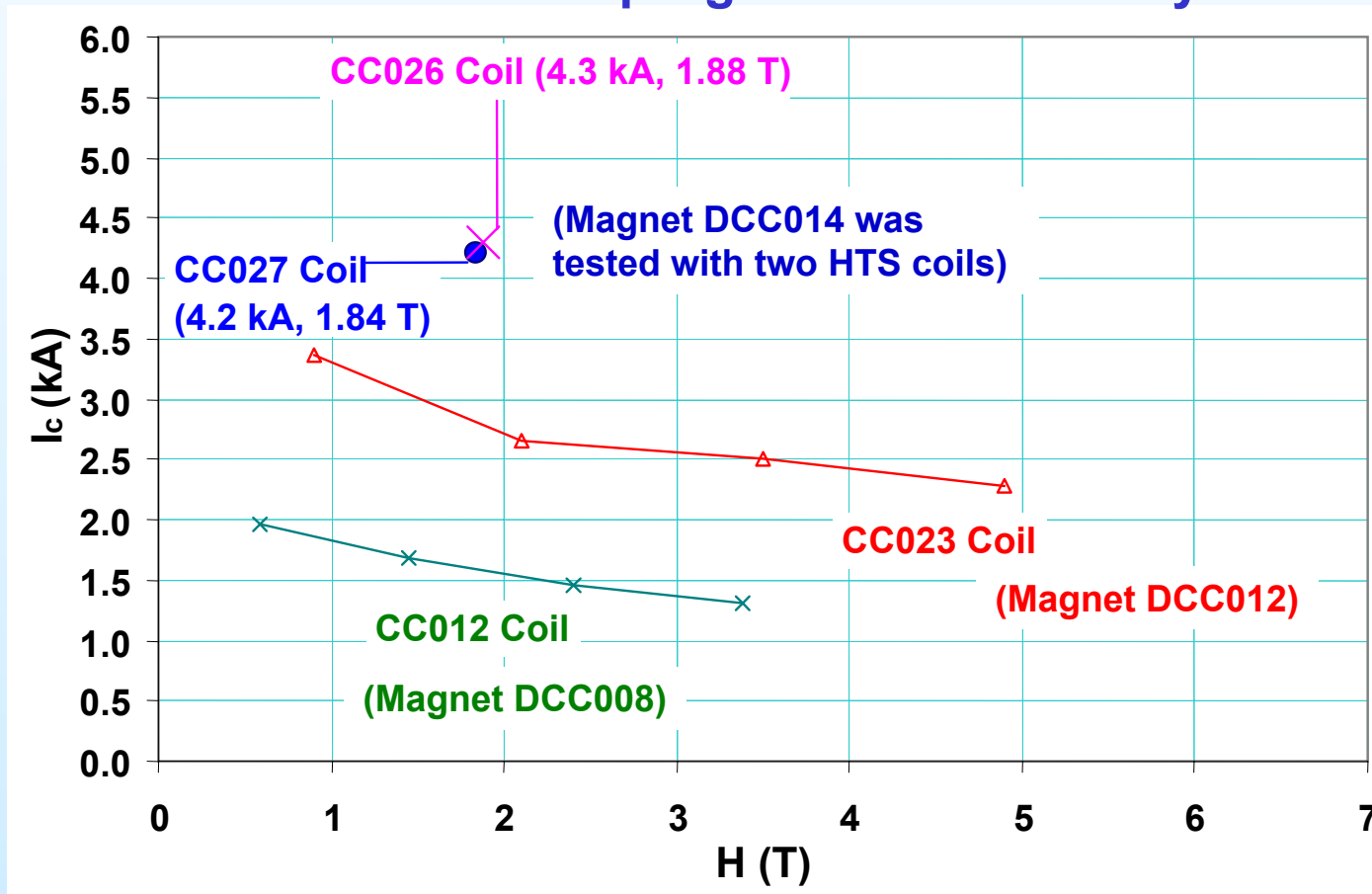
HTS cables now  
carry significant  
(over 4 kA)  
currents in  
magnet coils.

See poster for more details on room for still more improvements  
and on the quench protection issues of HTS coils.

# Progress in the Current Carrying Capacity of HTS Coils at Higher Fields

HTS coils can now be made with the cable carrying a respectable current at higher fields.  
(Note that the current carrying capacity does not fall much beyond 5 T).

A continuous progress is noteworthy.

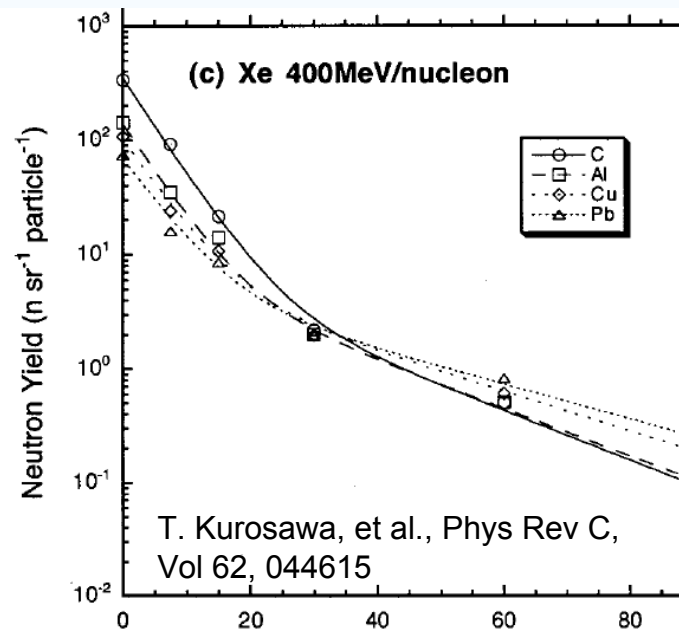
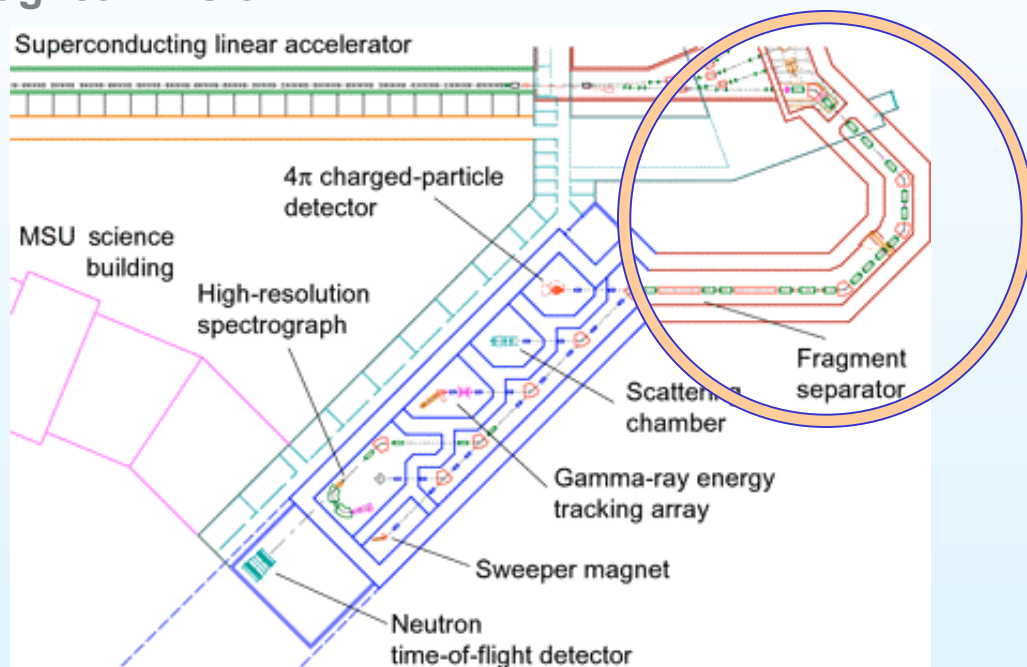


Poster on  
HTS Coils



# HTS Quads for Rare Isotope Accelerator

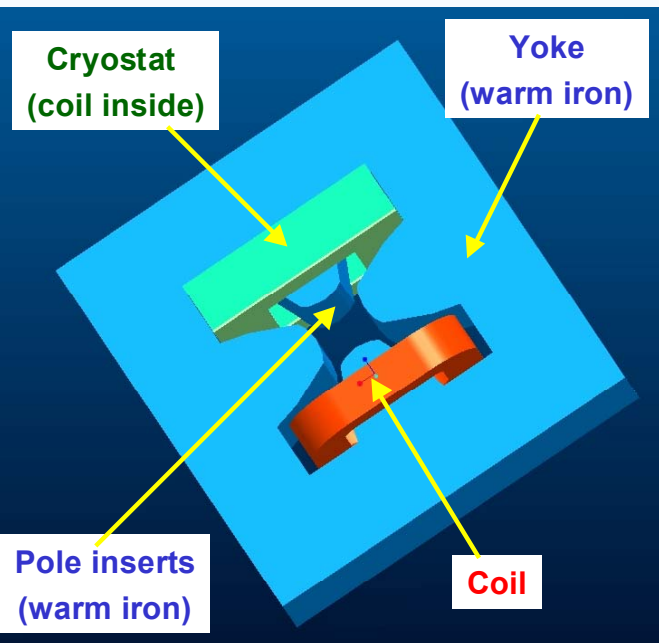
(A medium field, high operating temperature application of HTS)



- Beam loses 10-20% of its energy (several hundred kW) in the production target. This produces several kW of fast neutrons with yield peaking strongly at the forward angle.
- Quads are exposed to very hostile environment with a level of radiation ( $10^{19}$  neutrons/cm<sup>2</sup> in 0° to 30° region) and energy deposition (15 kW in the first magnet) never experienced by any magnet system before.

Need “*radiation resistant*” sc magnets, that can withstand large heat loads.

# HTS QUAD for RIA Fragment Separator

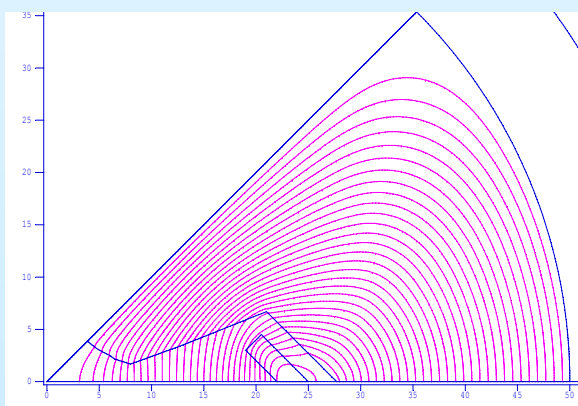


**Requirements: ~3 T field, operating at >20K.**

✓ **Can be achieved with the present HTS tapes.**

- HTS Quads can operate at a higher temperature (20-40 K instead of 4K). Higher operating temperature makes large heat removal (few hundred kW) more economical.
- In HTS magnets, the control of operating temperature can be relaxed by an order of magnitude. This simplifies cryogenic system.
- A warm iron yoke brings a major reduction in amount of heat to be removed at lower temperature.
- The coils are moved outward to significantly reduce the radiation dose.
- Insulation is a major issue. Use stainless steel tape as a radiation resistant insulation.

Coils inside the cryostat at the end of the magnet

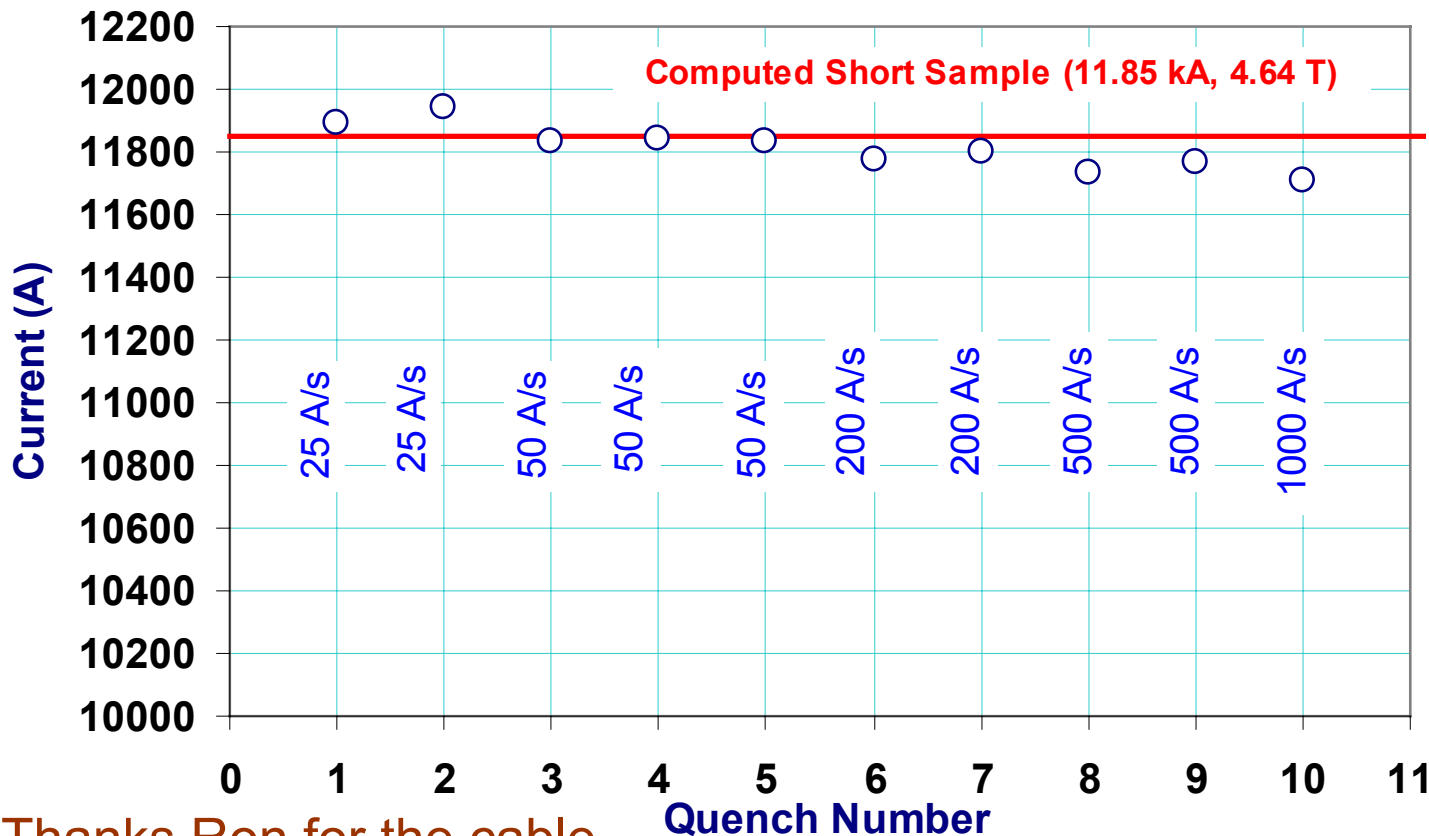


## Support for HTS R&D

- HTS cables and HTS coils have made a significant progress. They have been shown to carry a respectable current ( $\sim 4$  kA) in magnet coils. They have also been shown to work in high fields (NHFML).
- **Based on the above encouraging results with Bi-2212 conductor and in keeping with the long term R&D vision, the round wire program at OXFORD should be supported and React & Wind HTS cable magnet R&D should continue.**
- One among several potential accelerator magnet application of HTS is the critical IR magnets that are subjected to large energy deposition and require very high fields. Consider hybrid.

# Initial Experience with React & Wind $\text{Nb}_3\text{Sn}$ Technology Magnet at BNL

## DCC008: R&W $\text{Nb}_3\text{Sn}$ Common Coil Dipole



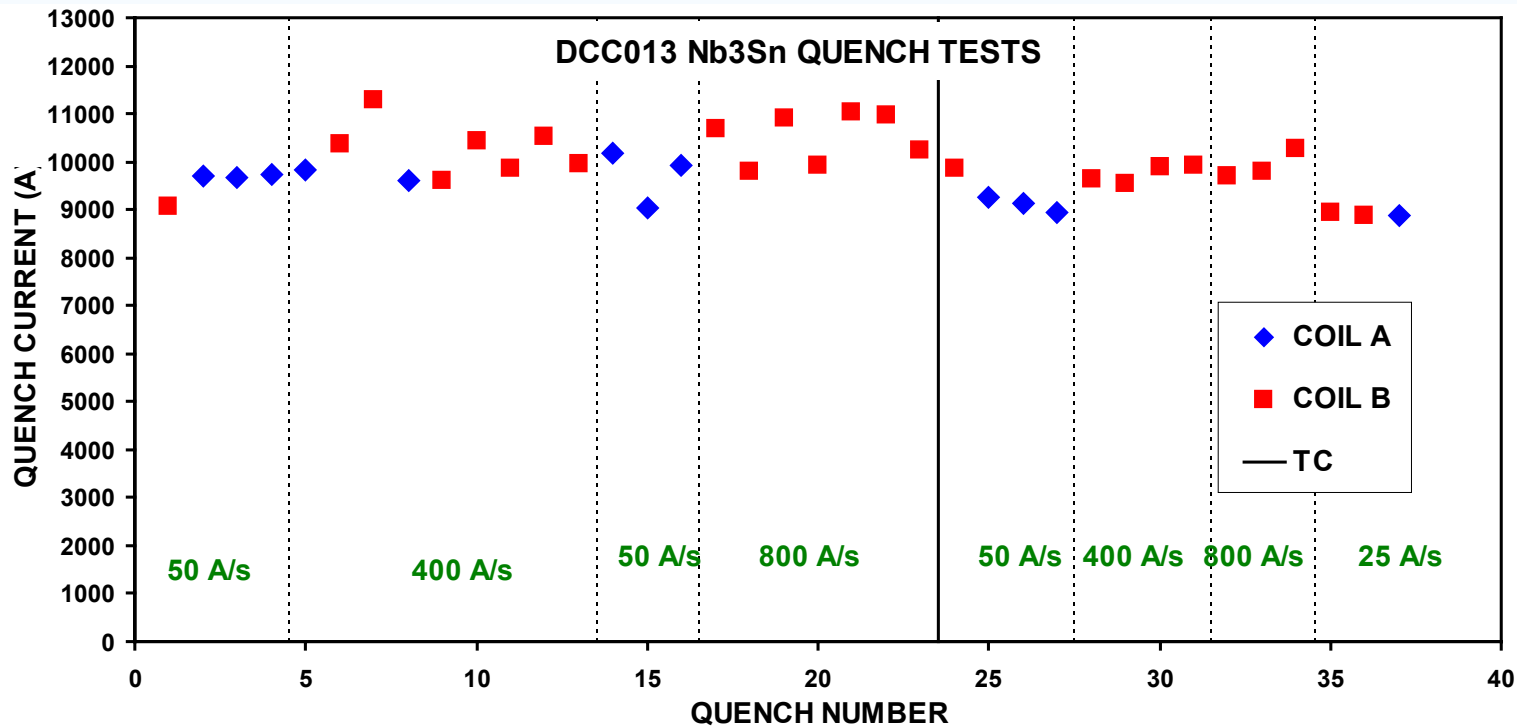
- Magnet reached the short sample in the first quench itself.
- The magnet was made with chrome-plated ITER cable.

E. Willen also successfully made coil with flexible wires.

Thanks Ron for the cable.

Good test result from the first “React & Wind” common coil dipole magnet itself  
> Perhaps too good; we got carried away with so nice performance coming so easily.

# Results of the Last React & Wind Magnet with High Performance Nb<sub>3</sub>Sn



- Unlike the first magnet, this reached only ~60% of the short sample.
- Quenches moved from one coil to other but were always in first turn – the most likely place of a systematic mechanical damage/degradation.
- Small gap between the two coils in common coil structure means that the turn-to-turn variation in field was relatively small.

## Experience with React & Wind Technology

### Does it reflect a learning curve or basic flaw?

- We got perfect result with the first magnet.
- Then we changed many things in an attempt to improve procedure/design and in preparation for 12 T design for background field magnet

Changes: conductor, mechanical design, construction technique, etc.

- In addition, a lot of handling was involved in the way coils were wound.
- Also, we worked with different technicians whenever and where ever we could find – a real challenge while working with brittle conductors.
- The above strategy worked well in brining good success in case of HTS with limited and little dedicated resources.
- But some time we wonder if above factors, individually or combined, point to a learning experience with Nb<sub>3</sub>Sn “React & Wind” or basic limitation?

The next attempt at BNL will be to go back to the original design (where the whole coil was impregnated in one piece), remove steps that have potential to cause damage and use proper coil winder (almost ready), etc.

## Experience with React & Wind Technology (Contd.)

### The scientific question is:

Are we facing basic limitation? Or the compromised performance is the result of our “attempted improvements”, and/or is learning curve?

- Recall, how long it took to make NbTi magnet work; and even today, some time how long it takes to make a new NbTi magnet work?
- A basic cable limitation/instability does not fully explain why all quenches are only in first turn of both coils and why the first magnet worked well. Also one can not say that no solution will ever come.



## Next Question

**Why continue with the development of the “React & Wind” technology for Nb<sub>3</sub>Sn magnets when “Wind & React” is shown to work?**

**Prudent reasons in next few slides.**

# Nb<sub>3</sub>Sn R&D and Production Magnets Wind & React Vs. React & Wind (1)

- Nb<sub>3</sub>Sn, like HTS, is brittle and is prone to damage during coil construction.
- “Wind & React” involves least handling with brittle conductors and therefore is the best bet, definitely for short R&D magnets. The technology has produced championship results in high field magnet program at LBL.
- “React & Wind”, when proven to work, appears to be the best bet for long and production magnet. The differences in the technical and construction issues between short and long magnets are minimum.
- The current experience of building long NbTi magnets in industry can be extrapolated to Nb<sub>3</sub>Sn magnets. The major difference is in winding coils with brittle materials. However, one can easily imagine that the current NbTi coil winding technology can be extrapolated with proper design and automation in winding tooling so that the strain on the conductor is minimum.
- “React & Wind” allows a variety of materials to be used for insulation and in other parts of the coil as they don’t go through high reaction temperature.

## **Nb<sub>3</sub>Sn R&D and Production Magnets** **Wind & React Vs. React & Wind (2)**

- In “Wind & React”, the differential thermal expansion build-up between various components of coil is proportional to the length of the magnet.
- This mismatch may build a large accumulated stress/strain on Nb<sub>3</sub>Sn, particularly in ends. It has to be shown how it can be avoided or handled.
- It needs to be shown that significant empty spaces will not be created in long coil as the turns are not held in place during the the reaction process. Large gaps, even when filled with epoxy, tend to create excessive training.
- The coil reaction enclosure and coil impregnation/support enclosure are significantly different. It needs to be shown that the coils can be delicately transferred from one to another and with no or very small gaps throughout.
- It is also possible that in the “Wind & React” case, the manufacturing requirements for long and/or production coils may require us to depart significantly from the techniques developed for short R&D magnets.

➤ **To summarize, there are many unanswered questions.**

## **Nb<sub>3</sub>Sn R&D and Production Magnets Wind & React Vs. React & Wind (3)**

- In light of several technical issues, and the fact that no long magnet has ever been built, it may be pre-mature to take either technology for granted --- either for small scale production or for large economical industrial production.
- In recent past we had few setbacks with “React & Wind”. However, given a relatively small effort made so far, it may be too pre-mature to say that those problems can not be solved or alternate solution, if necessary, is far away.
- Therefore, a credible magnet R&D should continue with “React & Wind” technology together with “Wind & React”.
- Make sure that we don't lock ourselves in or out of a technology and it's drawbacks or potentials too soon.

# Summary

- Given the good results with “React & Wind” Bi-2212 cable coils, and round wire performance from Oxford, the Rutherford cable program in US should be supported.
- It is too early to make a technology choice between “Wind & React” and “React & Wind” for Nb<sub>3</sub>Sn. It will be prudent, at this stage, to continue with both approaches, keeping long magnets and long road still ahead in mind.